Keynote

Supporting Multi-national Environmental Conventions and Terrestrial Carbon Cycle Science by Remote Sensing

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Abstract

Climate change and environmental degradation are issues of major concern amongst the general public in most parts of the world, as our current actions affect us now and for generations to come, at any level from local to national, to regional and global. In efforts to curb and reverse the current destructive trends, a number of environmental conventions and declarations have been discussed and, in some cases, ratified. To adequately follow-up implementation however, requires the availability of systems for monitoring and surveillance of the environment and its changes over time, and given the spatially extensive, cross-border nature of the human-induced and natural phenomena concerned – e.g. fire, land cover change, drought - Earth Observation techniques have a natural potential to substantially support this cause, if properly integrated with field measurements and ancillary data.

This paper describes the Kyoto & Carbon Initiative, which is an international collaborative project initialised in 2000 by NASDA (since Oct. 2003 known as JAXA), that is set out to support data- and information needs raised by certain multi-national environmental conventions and by global carbon cycle science, through provision of data products and high level information derived from ALOS, JERS-1 and ADEOS-II data [1]. The conventions primarily in focus are the UNFCCC Kyoto Protocol and the Ramsar Convention on Wetlands, to which fine-resolution, multi-scale information about the status and changes in forests and wetlands will be derived. There is apparent synergy with terrestrial carbon cycle science information needs, where improved spatial information about carbon pools, sources and sinks at local, regional to global scales are of high priority. The Kyoto & Carbon Initiative is also set out to support the UN Millennium Development goal on water access, as well as to the UN Convention to Combat Desertification.

Recognising the limited usefulness of the fragmented and local-focus data observation schemes characteristic for most fine resolution Earth Observation missions to date, dedicated Data Acquisition Strategies are being implemented for ALOS (launch 2005) and ADEOS-II (Dec. 2002 – Oct. 2003), with particular emphasis on ALOS' polarimetric L-band Synthetic Aperture Radar (PALSAR) and the 250 metre resolution Global Imager (GLI) sensor on ADEOS-II.

1. Background

1.1 The UNFCCC and the Kyoto Protocol

Climate change, caused by the rapid and uncontrolled increase of greenhouse gases in the Earth's atmosphere during the past 150 years, is a major public, political and scientific concern worldwide. Public concern resulted in the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and subsequently the Kyoto Protocol (1997), which demonstrate an official acknowledgement of the climate change phenomenon as such, as well as a recognition by most national policy makers that immediate cross-border actions are required to halt and reverse the current destructive trend. If ratified, the Kyoto Protocol will provide legally binding national emission reduction commitments and a timetable for implementation. Although politically controversial, the Protocol not only constitutes a landmark agreement for the global environment, but also for the international scientific community in that it puts political pressure for quantitative measurements of carbon sources and sinks with high, verifiable accuracy.

1.2 Global carbon cycle science

Viewing the climate change issue in a broader context than the Kyoto Protocol, the central role of the global carbon cycle has long been recognised by the international science community. The major concern here is incomplete understanding of the processes that govern the global carbon cycle, and the large uncertainties that are associated with current models and measurements. These uncertainties are partly results of lack of appropriate data or inadequacy of existing data sets. This deficiency is being addressed by the Integrated Global Observing Strategy Partnership (IGOS-P), which calls for a united multi-disciplinary scientific effort to resolve the present uncertainties, through the establishment of a dedicated global carbon cycle observation strategy. This strategy involves characterisation of the terrestrial, atmospheric and oceanic components of the carbon cycle by synergetic utilisation of *in situ*, modelling and other measurement techniques, including remote sensing.

Although carbon cycle science thematically is more exhaustive than the Kyoto Protocol, we note that both relate to the same basic information needs—that for accurate measurements of carbon sources and sinks—and research and support to one topic will thus inevitably also benefit the other.

1.3 The Ramsar Convention on Wetlands

The Ramsar Convention, signed 1971 in Ramsar, Iran, is an intergovernmental treaty, which provides the framework for national action and international co-operation for wetlands and their resources. The mission of the convention is the conservation and wise use of all wetlands through local, regional and national actions and international co-operation, as a contribution towards achieving sustainable development throughout the world (Ramsar COP8, 2002). The Ramsar Convention relies on voluntary actions by the signatory parties—thereby making it less controversial than the Kyoto Protocol—and it aims to halt and reverse the global trends of wetland degradation and destruction through the dissemination of information, involvement of local communities and establishment of sustainable management plans.

Wetlands International is an official International Organisation Partner of the Convention and acts as a specialist adviser and provider of data on wetland inventory as well as managing, under contract, the Convention's Ramsar Sites Database. The importance of remote sensing technology in this context is evident as adequate access to up-to-date spatial and temporal information about the wetlands and their catchment basins is a fundamental component in the development of wetland management plans for conservation and sustainable utilisation.

While not explicitly addressed by the Ramsar Convention, it is furthermore well known that both natural and anthropogenic wetlands (e.g. rice paddies) constitute significant sources of atmospheric methane, CH_4, thereby linking also the wetlands issue to carbon science. As the emissions from wetlands are poorly quantified over regional to global scales, improved understanding of wetland inundation dynamics is of high priority in the climate change context.

1.4 WSSD & UNCCD

Adequate access to freshwater for all people in the world is a critical need, which has been raised during several international meetings and fora during the past few years, most notably during the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002. The WSSD Implementation Plan states the over-reaching goal to "halve, by the year 2015, the proportion of people who are unable to reach or afford safe drinking water as outlined in the UN Millennium Declaration...". The situation is most acute in arid and semi-arid areas, with particular emphasis on the African continent and central Asia, which also are the regions most severely affected by land degradation and desertification, as addressed by the 1994 UN Convention to Combat Desertification (UNCCD).

Remote sensing data can contribute as a tool for water prospecting, as well as for monitoring and mapping of land vulnerability in support to action plans aiming to halt and reverse degradation.

2. The Kyoto & Carbon Initiative

2.1 Outline

The Kyoto & Carbon Initiative is based on the conviction that remote sensing technology can play a significant role in supporting some of the information needs posed by both certain environmental treaties and by carbon cycle science. In a report by the Terrestrial Carbon Theme Team of IGOS-P, the need for such support was voiced: *"The challenges [to a terrestrial carbon observation strategy] are to ensure that important existing observations continue and key new observations are initiated [and] to identify activities and agencies willing to contribute to establishing global carbon observations... "* [2].

The Kyoto & Carbon Initiative should be seen as a response by JAXA to this call.

Led by the Earth Observation Research and Applications Center (EORC) of JAXA, the Initiative is being established as an international collaborative project, building on the existing network established within the JERS-1 Global Forest Mapping project [3]. A decentralised organisation is being implemented, set up around four main themes, each supported by the K&C systematic data observation strategies:

(i) Forest and Land Cover Change
Focused to support the Kyoto Protocol and the part of the carbon research community concerned with CO_2 fluxes from terrestrial sinks and sources.

(ii) Wetlands & CH_4
Serving Ramsar information needs and the significance of wetlands from a CH_4 perspective.

(iii) Desert & Water
Addressing issues relevant to water supply and land degradation in arid areas.

(iv) Mosaic Products
Generation of satellite image mosaics, primarily to be utilised as intermediate products by the K&C science team, the mosaics will also be made available in the public domain.

2.2 Systematic Data Observation Strategies

2.2.1. Fragmented data archives
Climate change and environmental degradation are cross-border multi-scale phenomena, which require the availability of systematic and consistent data sets at local, regional and global scales. This fundamental need for coherent multi-scale data applies both to environmental convention support as well as in the carbon cycle context, and it is highlighted in Article 10(d) of the Kyoto Protocol which states that countries shall *"co-operate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, [and] the adverse impacts of climate change... "*.

Provision of systematic observations and establishment of data archives for long-term studies is clearly one of the *potential* strengths of Earth Observation from space. However, fine resolution remote sensing data are generally not acquired homogeneously over large areas, but instead most often collected with local focus over sites that have been specifically requested by commercial or scientific users. This results in inconsistent and fragmented data archives that are inadequate for any application that require extrapolation of locally developed methods and results to a regional or global scale context.

The need for improved data observations is acknowledged by IGOS-P, who states that *"it is evident that further progress in our understanding of the global carbon cycle and its likely future evolution depends on improved observations of the terrestrial carbon processes"*[2]. Hence, if we are indeed serious in our objectives to support climate change research and convention support on anything but local scales, it is imperative that data acquisitions are planned in a systematic manner, with regional-continental scale coverage, fixed sensor characteristics, and adequate temporal repetition frequency (Figure 1).

JAXA has acknowledged the critical need for consistent data and by setting aside a significant share of the ALOS PALSAR and ADEOS-II GLI acquisition capacities for this purpose, allowed the establishment of an unprecedented, global Data Observation Strategy in support to climate change research and environmental conventions, as outlined within the Kyoto & Carbon Initiative.

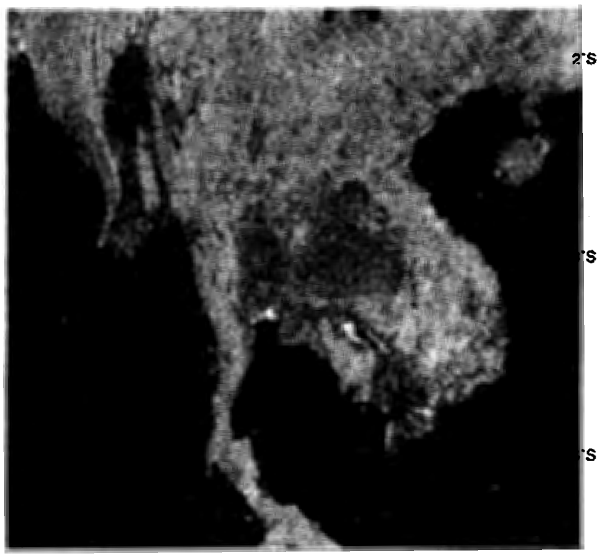

Figure 1. Mainland Southeast Asia. Example of systematic data observations over regional scales: 35 JERS-1 SAR passes acquired consecutively during a 35-day period in Jan.-Feb.1997.
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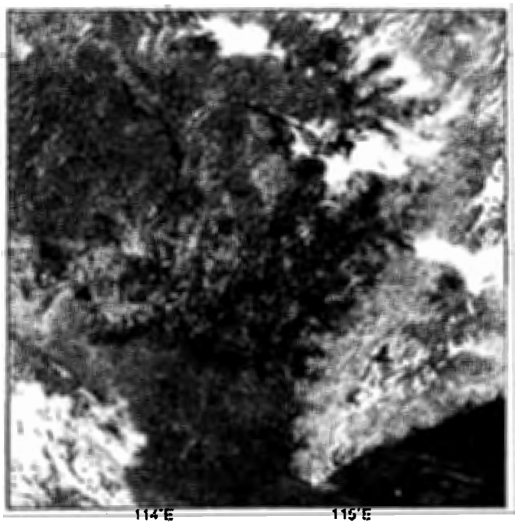

Figure 2. Extract from a wide swath (1600 km), medium resolution (250 m) coverage by ADEOS-II Global Imager (GLI) over southern Kalimantan, Indonesia, 21 February, 2003. © NASDA

2.2.2 The PALSAR Observation Strategy

The Advanced Land Observing Satellite (ALOS) is scheduled for launch in 2005 and it will operate with 46-day repeat orbit and 70 km swath. The Synthetic Aperture Radar (PALSAR) on ALOS is an active microwave instrument, which thus can acquire data regardless of sunlight and cloud cover. And like its predecessor on JERS-1, the radar instrument operates with a wavelength (L-band; 23.5 cm) that is particularly sensitive to vegetation structure and inundation state, hence making it particularly suitable for environmental monitoring.

In the design of the PALSAR systematic data observation strategy, focused on the collection of data for geo- and biophysical parameter retrieval over regional scales, the following basic acquisition concepts - outlined in [4] - have been taken into account:

1. Spatial and temporal consistency over regional scales (i.e. continental-scale coverage within short time windows);
2. Adequate revisit frequency (i.e. acquisition repetition adapted to the individual forest-, wetlands- and desert thematic needs);
3. Accurate timing (targeting acquisitions to the most suitable season);
4. Consistent sensor configuration (limiting the number of sensor modes used, to increase intercomparability and regional homogeneity, and to minimise internal acquisition conflicts);
5. Long-term continuity (annual repetition of the strategy to the end of mission).

The draft K&C observation strategy for PALSAR comprises full global acquisitions at fine resolution (20 metres) twice per year during the mission lifetime. Observations are timed to be performed once during summer season (or dry season in the tropical zone) and once during the winter season (tropical rainy season). The intention is to establish an extensive global archive of PALSAR data, in which consistent time-series of fine resolution data is to be available for any arbitrary point on the Earth. This part of the acquisition plan is primarily designed to fulfil the data requirements pertaining to the Forest and Land Cover Change, and the Desert & Water themes, and it comprises the annual acquisition of more than 235,000 PALSAR scenes at fine resolution.

In support to the Wetlands & CH4 objectives, in which more frequent acquisitions than semi-annual are required to capture the rapid seasonal changes in wetland inundation or paddy growth that occur (see 2.4 below), every 46-day coverage during one full year using the 100 metre resolution (ScanSAR) mode are planned. These cover a selection of significant wetland and paddy areas on the globe, amounting to some 13,000 ScanSAR scenes to be acquired annually.

2.2.3 The GLI Observation Strategy

ADEOS-II (Advanced Earth Observation Satellite II) was in launched in December 2002, but was in operation only until October 2003, due to a technical failure. Amongst the six remote sensing instruments on-board, the payload included the Global Imager (GLI) - a 36-channel multi-spectral scanner. Six of the GLI bands were dedicated for terrestrial use, resembling MODIS and ETM+ in their spectral definitions, but all operating with a spatial nadir ground resolution of 250 metres. The image swath was 1600 km and the revisit cycle 4 days (Figure 2).

The Observation Strategy for GLI was designed for 4-day repeat coverage over the Asian region, over which direct downlink via Data Relay Satellite (DRTS) could be performed. Over regions out of reach for DRTS, coverage will be less frequent due to limitations in the on-board storage. The GLI-250 acquisition strategy is described in [5].

2.2.4 An archive for the future

It should be emphasised that not all data outlined within the Observation Strategies are foresee, or even intended, to be processed immediately. Rather, one of the basic objectives is to provide policymakers and science community with comprehensive data archives from which consistent PALSAR and GLI time series can be found for an arbitrary location of interest. It is believed that this type of data archive will prove useful also for applications far beyond those of convention support and carbon cycle science, for a long time to come.

2.3 The Forest and Land Cover Change Theme

2.3.1 Kyoto information requirements

While it even may be considered an obligation by the space agencies (of the ratifying countries) to actively support the UNFCCC Kyoto Protocol, it is not entirely clear what the Protocol information requirements are, and how - and if - they can be supported by remote sensing technology. In a review performed by the ISPRS in 1999 to investigate this particular issue [6], revised in 2003 [7], five main areas of potential support were identified:

1. Provision of systematic observations of relevant land cover (Art. 5, 10d);
2. Support to the establishment of a 1990 carbon stock baseline (Art. 3.1);
3. Detection and spatial quantification of change in land cover (Art. 3.3, 3.4, 12);
4. Quantification of above-ground vegetation biomass stocks and associated changes therein (Art. 3.3, 3.4, 12);
5. Mapping and monitoring of sources of anthropogenic CH_4 (Art. 3, 5, 10).

While topic #2 is out of scope for the Kyoto & Carbon Initiative, the remaining four points are very relevant. The requirement for systematic observations (#1) has been adequately addressed in the Systematic Observation Strategies for PALSAR and GLI described above and will not be dealt with further here. The last point on anthropogenic CH_4 sources (#5) will be discussed under the Wetlands Theme below (§2.4). Topics 3 and 4 however, relating to detection and quantification of changes in forest- and land cover, constitute the main focus within this theme.

2.3.2 Kyoto definitions

Central in this context is Article 3.3 in the Protocol and the key concepts of forest and afforestation, reforestation and deforestation (ARD). *Forest* was defined at the UNFCCC COP7 meeting in Marrakesh as *"a minimum area of land of 0.05-1.0 hectares with tree crown cover, or equivalent stocking level, of more than 10-30 % and containing trees with the potential to reach a minimum height of 2-5 m at maturity"* [8]. The definition to be adopted by a country is optional within the intervals given for minimum area and crown cover.

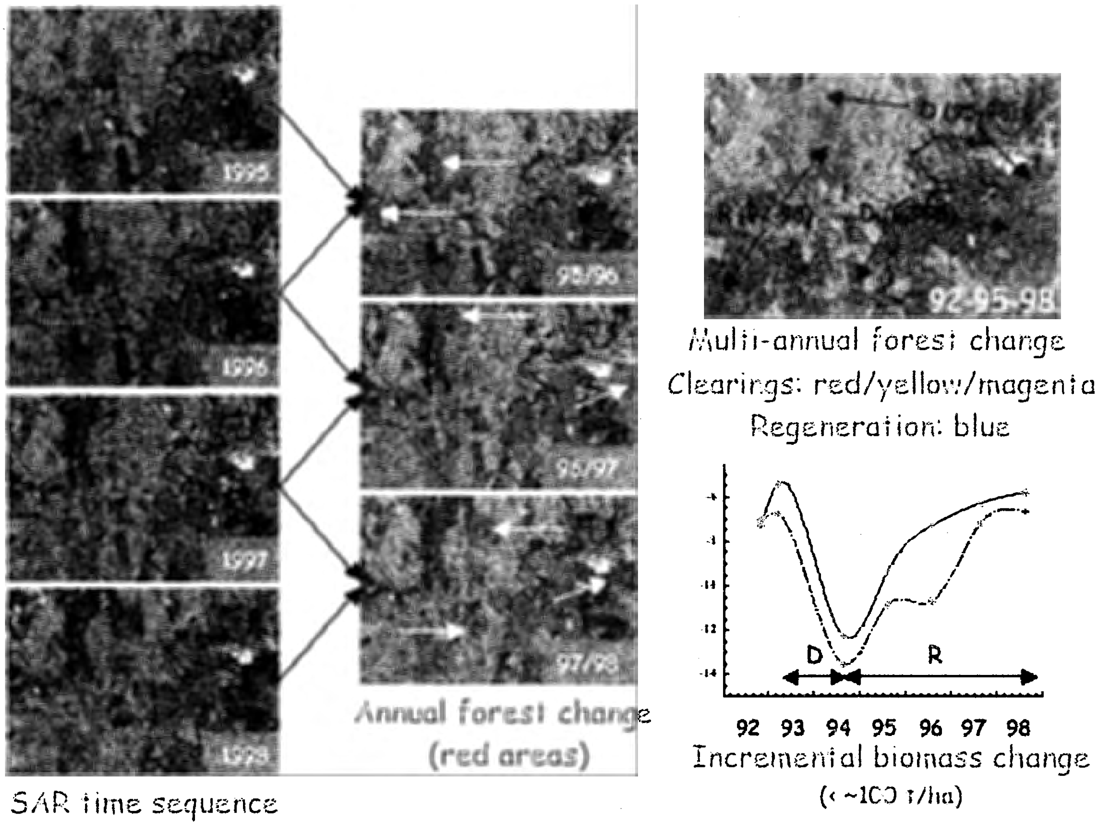

Figure 3. Simple approach for detection and spatial quantification of change in land cover ("ARD monitoring"), by using a consistent time-series of SAR data (far left), acquired systematically during the same season every year. Annual change images (centre) indicate clearfellings performed between two consecutive years, which appear in red colour. A multi-year image composite (right, top) also reveals regeneration (blue colour, indicated by "R"). The diagram (right, bottom) illustrates changes in radar backscatter over time, flowing deforestation (D) and subsequent, regeneration. © NASDA/METI

Afforestation is defined as direct human-induced (DHI) conversion of land that has not been forested for a period of at least 50 years, while *reforestation* implies DHI conversion of previously forested land that did not contain forest on Dec. 31, 1989. *Deforestation* is simply defined as the DHI conversion of "forest" to "non-forest" [8].

Important to note is that forest and ARD activities within Kyoto are defined on the basis of change in *land use*, rather than of land cover as is observed by remote sensing. This implies that distinction of land belonging to either "forest", or the inverse "non-forest" category, and in turn recognition of A, R or D as changes between these categories, cannot be performed directly or solely in remote sensing data, without use of *in situ* or other land-use based information sources.

2.3.3 Carbon science requirements

In the context of terrestrial carbon cycle science, the basic information requirement is raised by IGOS-P: *"Estimates of above- and below- ground biomass provide fundamental information on the size and changes of the terrestrial carbon pool as land use and associated land management practices change"* [2].

Synergy with Kyoto information requirements is apparent, although the focus is on *land cover*, comprising both human-induced and natural activities. With improved understanding of the carbon budget a scientific goal, accuracy requirements are less stringent than what can expected for Kyoto Protocol implementation and verification (not yet defined), where CO_2 equivalent emissions will be associated with a financial value.

2.3.4 Forest stocks and changes

With consistent annual time series of fine resolution PALSAR data available (§2.2.2), plain identification and subsequent spatial quantification of changes in forest cover is a rather straightforward task, which to a large extent can be performed in an operational manner. The 0.05-1.0 ha minimum area requirement within Kyoto [8] implies an effective ground resolution of 20-100 metres, which is within the range of the PALSAR capacity. Figure 3 illustrates the appearance of such land cover changes in a 4-year time series of JERS-1 L-band SAR data. Although not quantified in terms of carbon changes, spatial knowledge about *where* and *when* changes have occurred, and *how large* areas that are affected, is important information to be utilised in the accounting process in combination with other data.

Retrieval of above-ground biomass stocks is a Holy Grail for carbon budget research, and while it is not an explicit Kyoto requirement, quantification of biomass loss following for instance a deforestation event, does require an estimate of the biomass levels prior to clearfelling. While biomass stock inventories in mature forest stands above the L-band sensitivity range must be ruled out, retrieval of biomass-related biophysical parameters in sparse and regenerating areas may be foreseen. It is included in the Initiative as an R/D topic, with focus on the boreal zone with biomass levels within the L-band SAR sensitivity range.

Biomass retrieval algorithms can be improved with *a priori* information about species distributions and land cover available. Archived ADEOS-II GLI data will be utilised to generate regional-scale land cover classifications at 250 m resolution over the Asian continent to complement the 1 km classifications presently available.

2.4 The Wetlands & CH4 Theme

2.4.1 Wetlands and CH4

Irrigated rice is a significant anthropogenic source of CH_4 which is not currently included within the Kyoto Protocol, but may have to be accounted for in the future. Rice paddy is easily distinguishable in time series of SAR data, from which cultivated area, timing and number of crop cycles can be obtained (Figure 4).

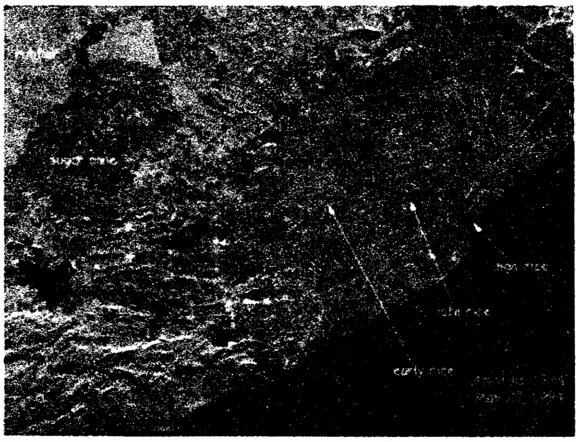

Figure 4. Irrigated rice (Perlis, Malaysia). Multi-temporal JERS-1 SAR. Rice paddy can be distinguished from other land use/land cover classes through its characteristic temporal signature. Local variations in the crop cycle are visible as green and blue. © NASDA/METI

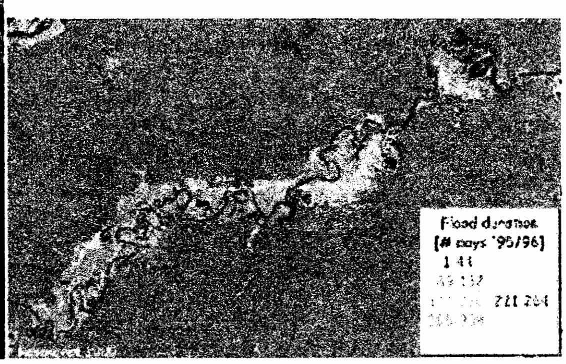

Figure 5. Flood duration map (Jaú river, Amazonas, Brazil) derived from a time-sequence of 9 consecutive JERS-1 SAR scenes, acquired during one seasonal flood cycle (Oct. 1995 - Oct. 1996). © NASDA/METI

Amongst non-anthropogenic CH_4 contributors, floodplains and wetlands areas are sources of major importance, and IGOS-P remark that *"satellite observation techniques and modelling tools should be developed to estimate methane fluxes from wetlands"*[2]. While CH_4 fluxes *per se* cannot be measured by remote sensing, key input parameters to emission models in forms of the spatial extents of flooding and its variations over time can be obtained, as demonstrated by JERS-1 SAR (Figure 5). The uniqueness and importance of L-band SAR for mapping of inundated vegetation cannot be overly emphasised, as it is the only space-borne sensor configuration with the capacity of deriving such information.

2.4.2 Wetlands and conservation

The Ramsar Convention Bureau has officially endorsed the Kyoto & Carbon Initiative, and has together with JAXA and Wetland International identified three areas where the Initiative can collaborate with, and support the convention [9]:

1. Inundation mapping;
2. Disturbance monitoring:
3. Support to a global wetlands inventory:

Inundation mapping;

Mapping of spatio-temporal characteristics of inundation phenomena in global wetlands is not only an issue for CH_4 modelling, but also from an environmental aspect as seasonal flooding is a key ecological driver. Spatio-temporal information about hydrological dynamics is at present generally not available and would be highly valued to support the development of sustainable wetland management plans. Scales of interest range from semi-continental (e.g. Amazon, Congo basins), regional (e.g. Pantanal wetlands) to local (individual Ramsar-designated sites).

PALSAR data acquired in 100 m resolution ScanSAR mode, with 46-days' repetition during a period of one full year, as outlined in the PALSAR Observation Strategy (§2.2.2) will be required to characterise the variations associated with forest inundation and rice cultivation.

Disturbance monitoring:

Identification and monitoring of human-induced and natural disturbances in both Ramsar-designated and other wetlands is another important remote sensing application. The PALSAR Observation Strategy plan for repetitive annual global fine resolution observations at 20 metres resolution will be utilised for identification and spatial assessment of changes, complemented with 250 metre GLI observations at weekly-monthly repetition.

Support to a global wetlands inventory:

As the locations and extents of wetlands in the world are not all recorded, identification and delineation of global wetland areas in support to the Ramsar Data Base, maintained by Wetlands International, is a third important contribution area where PALSAR and GLI data will be utilised. As the attributes, which characterise wetlands, differ widely, the usefulness of PALSAR and GLI data has to be evaluated on a case-by-case basis. Also the 100 metre JERS-1 SAR continental-scale mosaics generated within the Global Forest Mapping project [3] will be used to support the inventory.

2.5 The Desert & Water Theme

By incorporating the on-going SAHARASAR project [10] into the Kyoto & Carbon Initiative, we aim to support WSSD and the UN Millennium Declaration goal for access to safe drinking water. As microwave signal can penetrate dry sand layers, subsurface geomorphological and hydrological features can be revealed (Figure 6). To this end, JERS-1 SAR mosaics over Eastern Sahara have been generated in 2002. The area will be expanded to cover the entire Sahara desert and the Arabian Peninsula with dual-polarimetric ALOS PALSAR data.

2.6 International framework and scientific support

Links with national and international bodies involved in convention implementation and synergy and alignment with other international carbon- and forest related efforts—notably the CEOS Global Observations of Forest Cover (GOFC) project and the GTOS Terrestrial Carbon Observation (TCO) theme—is imperative for the Initiative, and to this end, an international Scientific Advisory Panel was established in 2001 to oversee and review the definition of the project. The 25-member panel consists of well-renowned scientists active in the fields of carbon modelling and biophysical parameter retrieval, SAR experts, representatives from Wetlands International, GTOS/TCO, FAO, GOFC, space agencies, universities and public research institutions.

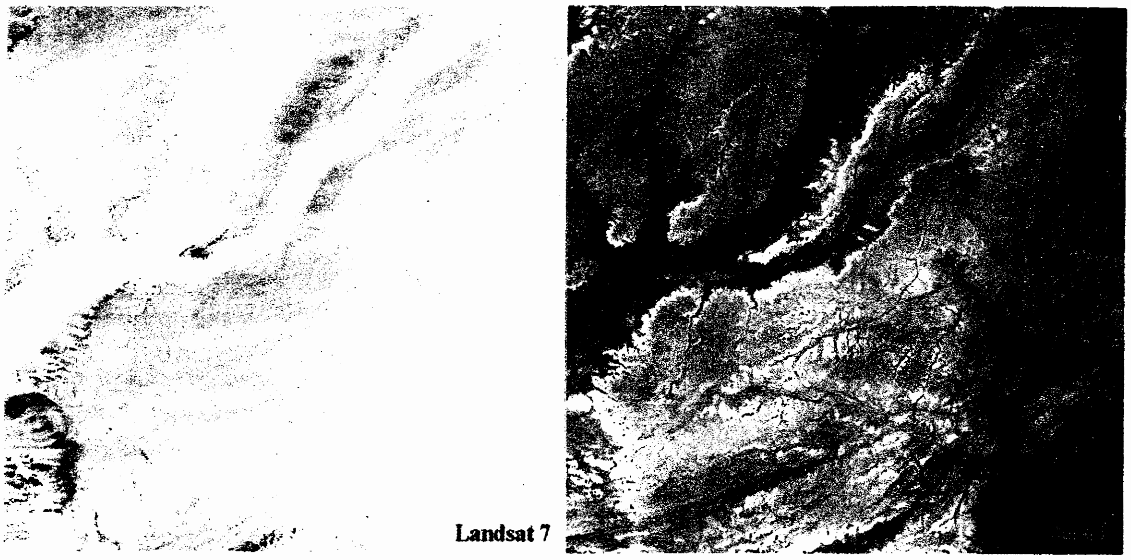

Figure 6. East Sahara as viewed by optical (left - LANDSAT ETM+ quick-look mosaic) and microwave (right - JERS-1 SAR) sensors. Devoid of soil moisture, microwave signals penetrate the dry sand layers to reveal paleo-hydrological structures and other sub-surface geomorphological structures. © NASA, © NASDA/METI

3. Acknowledgement

The present paper is a modified and up-dated version of [1].

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Kyoto & Carbon Initiative Home page: http://www.eorc.jaxa.jp/ALOS/kyoto/kyoto_index.htm